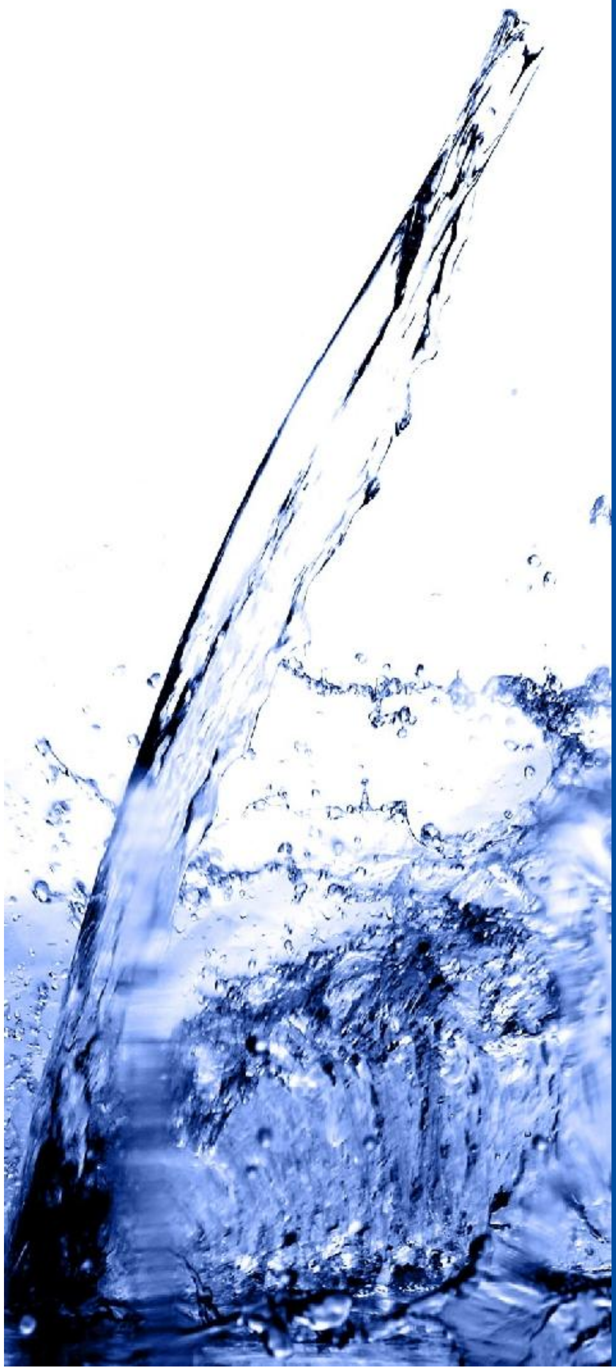


Nitrate Treatment Challenges

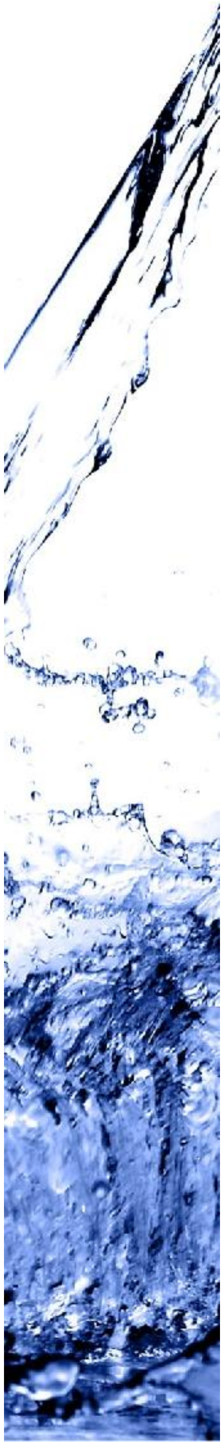
Ongoing Nitrate Treatment Studies

Jacobs Engineering Group Inc.

Chad Seidel, Ph.D., P.E.
Craig Gorman, P.E.

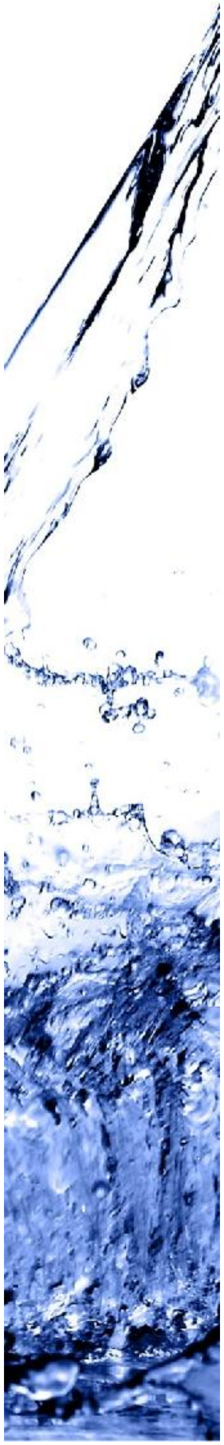
University of California, Davis

Jeannie Darby, Ph.D., P.E.
Vivian Jensen, E.I.T.



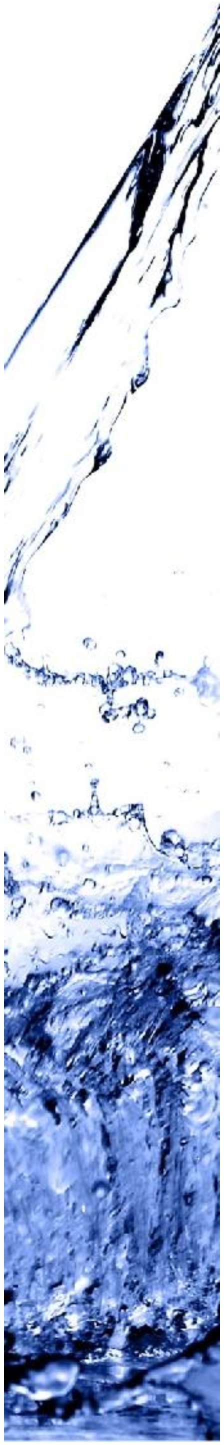
Overview

- Acknowledgements
- Associated Research
- Nitrate Occurrence and MCL Violations
- Nitrate Management Options
- Treatment Options and Selection
- Conclusions



Acknowledgements

- AWWA Technical & Education Council and Inorganic Contaminants Water Quality and Research Committees (including Susan Brownstein, CDPH!)
- CDPH SWRF Fund, Contract No. 06-55254
- Cal. State Water Resources Control Board, Contract No. 09-122-250



Associated Research

- *An Assessment of the State of Nitrate Treatment Alternatives* for AWWA (2011)

  http://www.awwa.org/Portals/0/files/resources/resource%20dev%20groups/tech%20and%20educ%20program/documents/TECNitrateReportFinalJan2012.pdf

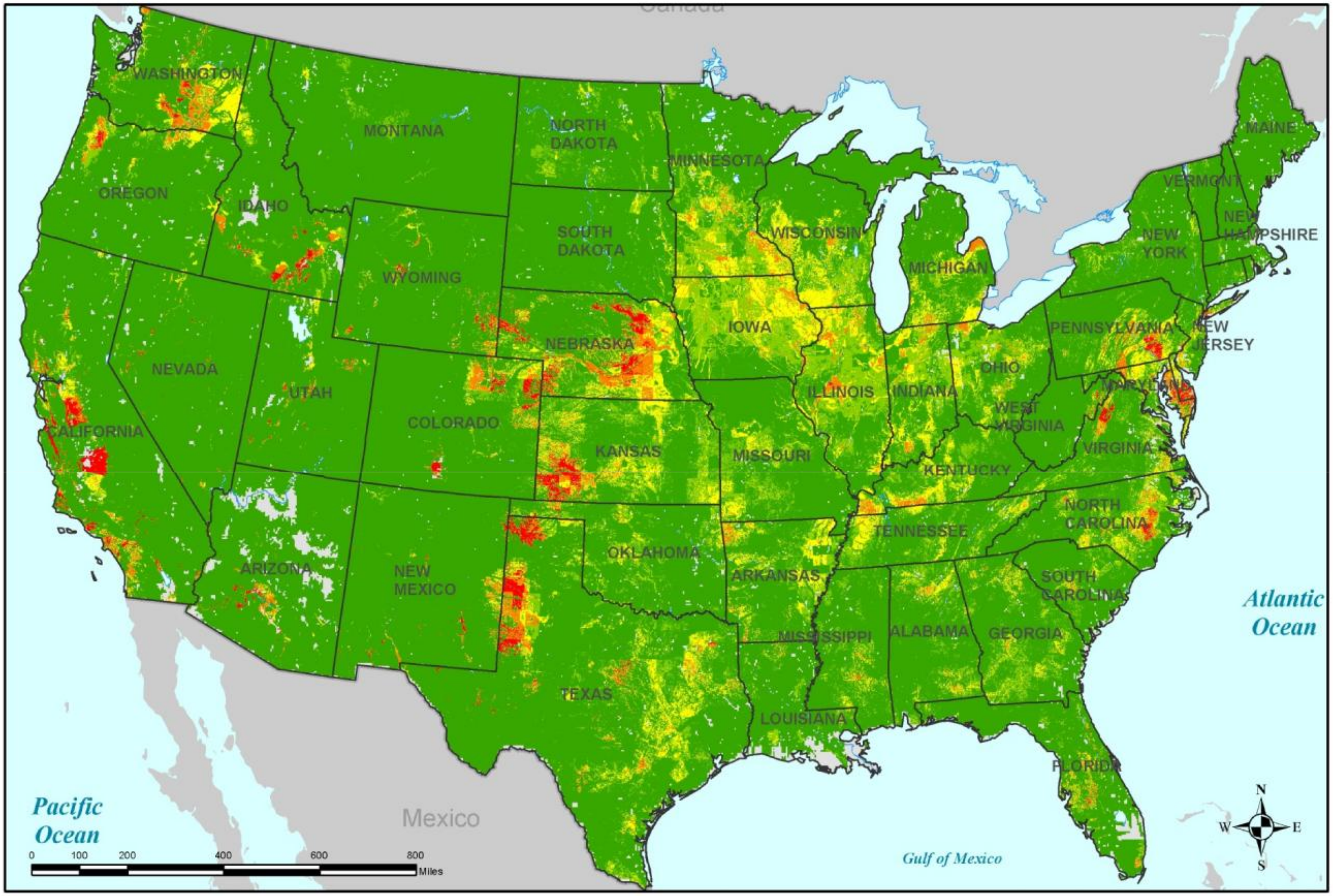
- California Nitrate Project, Implementation of Senate Bill X2 1 prepared for the California State Water Resources Control Board (Technical Report 6, 2012)

  http://groundwaternitrate.ucdavis.edu/

- The Center for Affordable Technology for Small Water Systems (Director: Dr. Jeannie Darby)

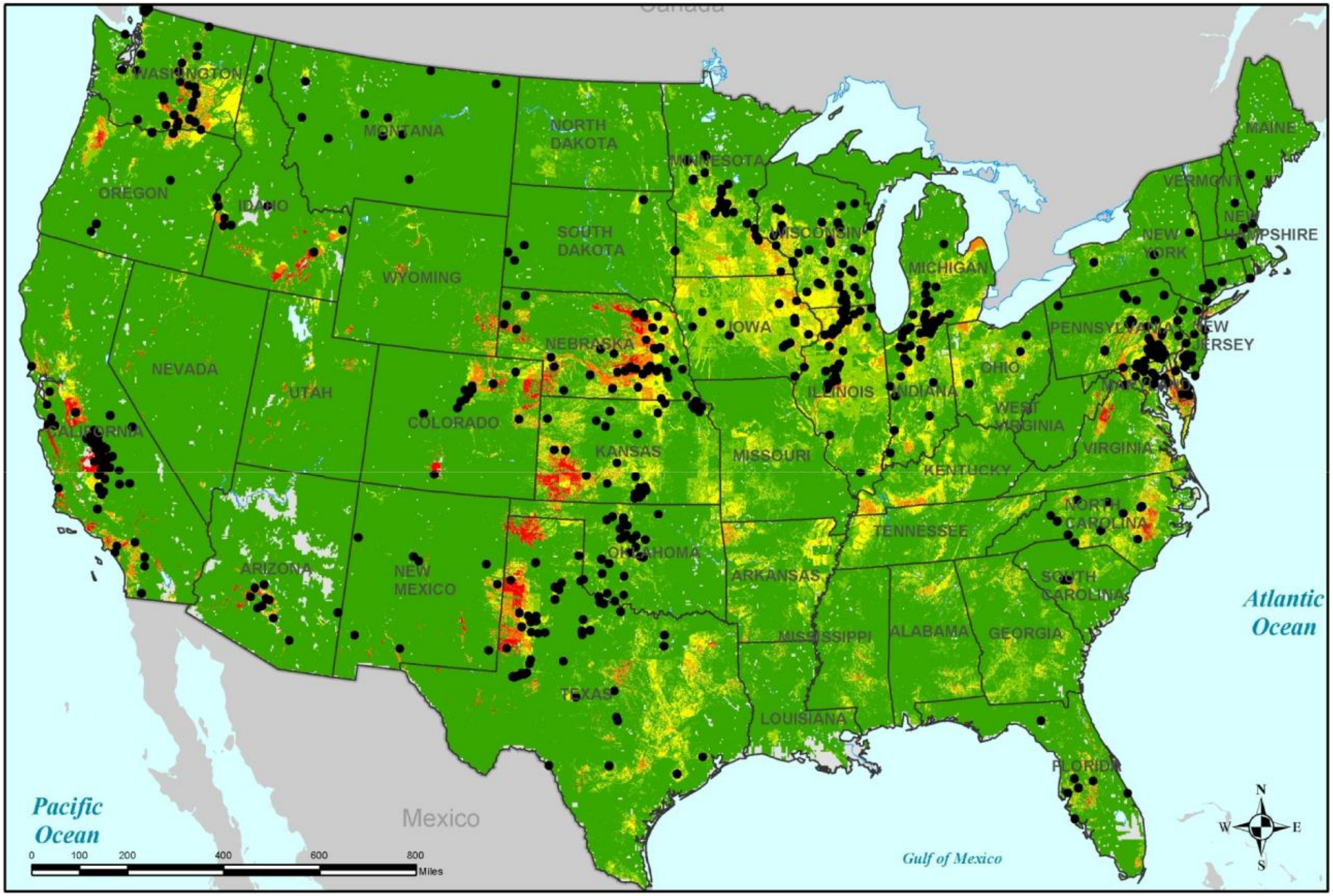
  http://smallwatersystems.ucdavis.edu/

- Jensen et. al., *Drinking Water Treatment for Nitrate*, Critical Reviews in Environmental Science and Technology, Accepted 2013



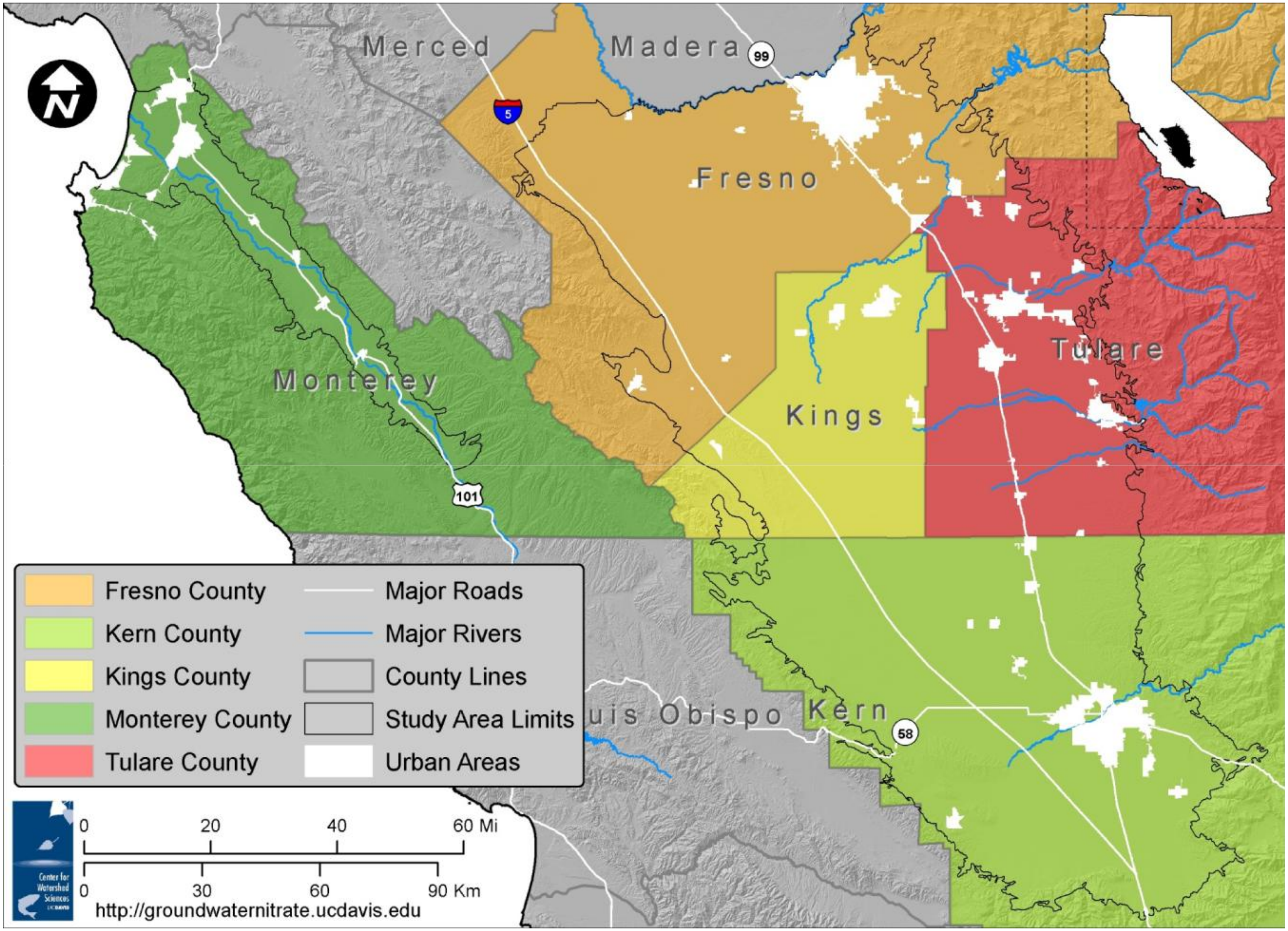
USGS Groundwater Nitrate Model
(Nolan & Hitt, 2006)

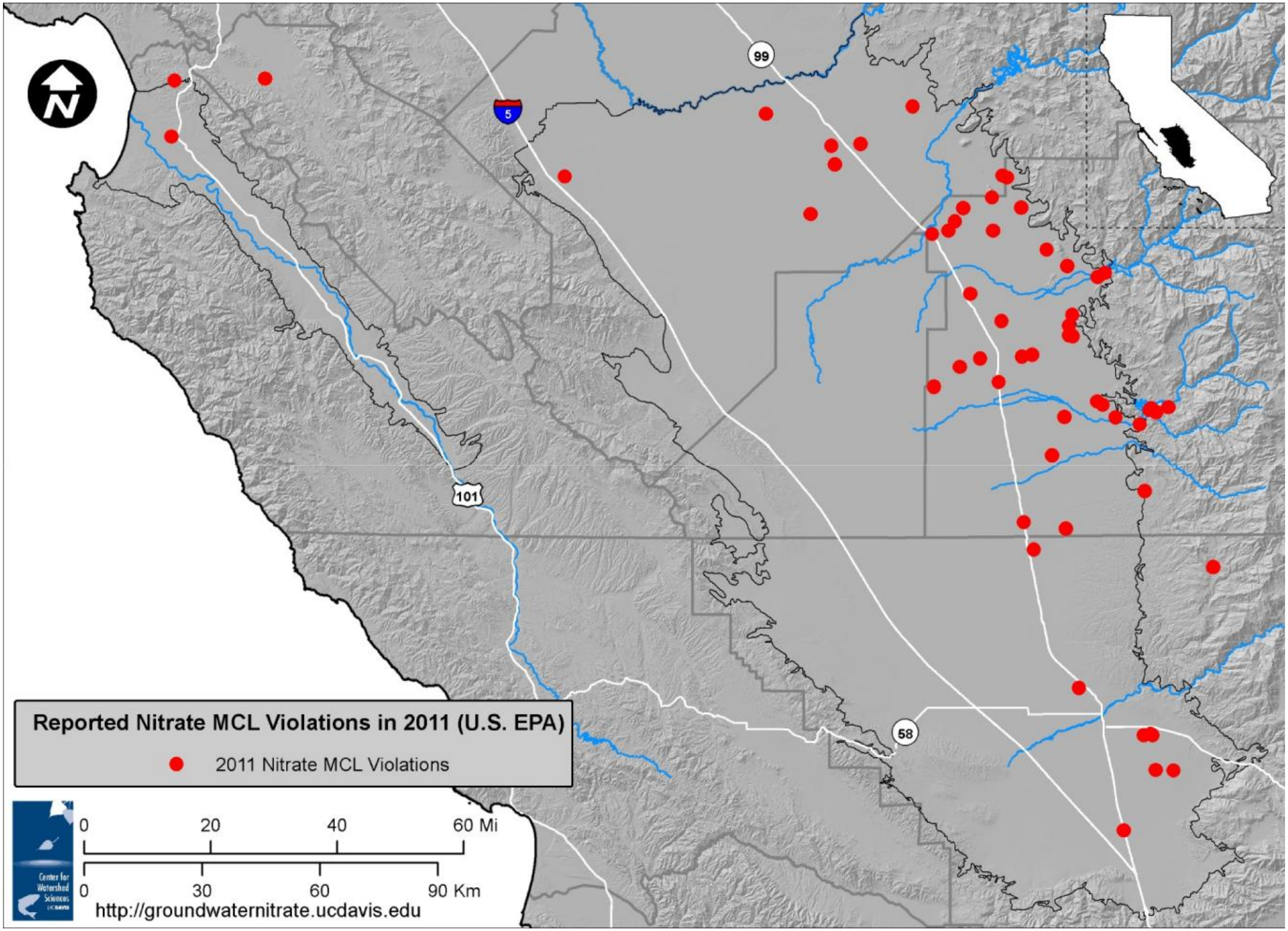
50 m Depth Simulation	
mg/L nitrate as N	5.01 - 10.0
0 - 1.50	>10
1.51 - 2.50	
2.51 - 5.00	

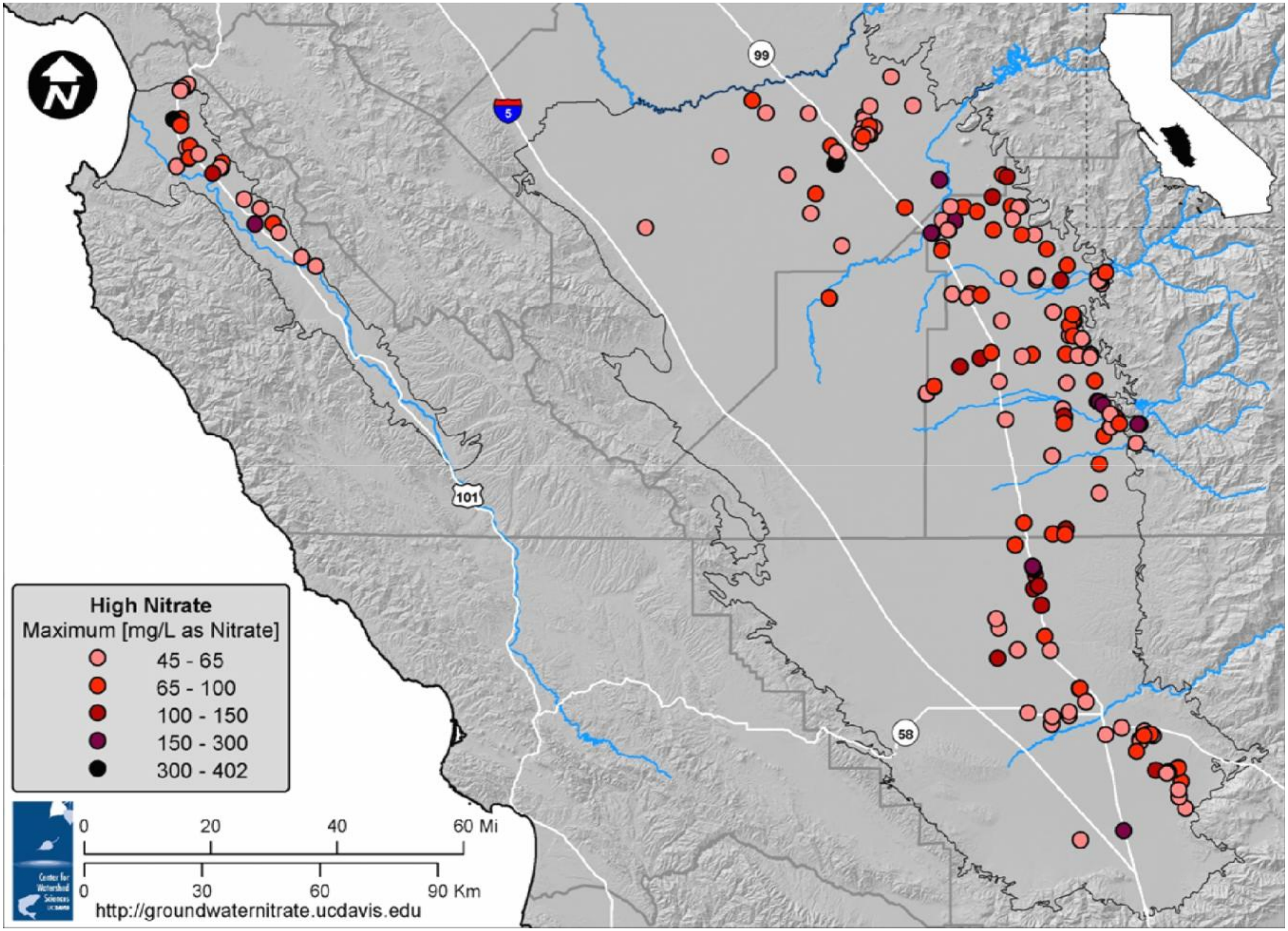


2011 Nitrate MCL Violations (U.S. EPA)
& USGS Groundwater Nitrate Model
(Nolan & Hitt, 2006)

50 m Depth Simulation
mg/L nitrate as N
- 0 - 1.50
- 1.51 - 2.50
- 2.51 - 5.00
- 5.01 - 10.0
- >10
- ●2011 Nitrate MCL Violations (U.S. EPA)


Merced
Madera
99
5
Fresno
Tulare
Monterey
Kings
101
uis Obispo
Kern
58
Fresno County
Kern County
Kings County
Monterey County
Tulare County
Major Roads
Major Rivers
County Lines
Study Area Limits
Urban Areas
0
20
40
60 Mi
0
30
60
90 Km
http://groundwaternitrate.ucdavis.edu

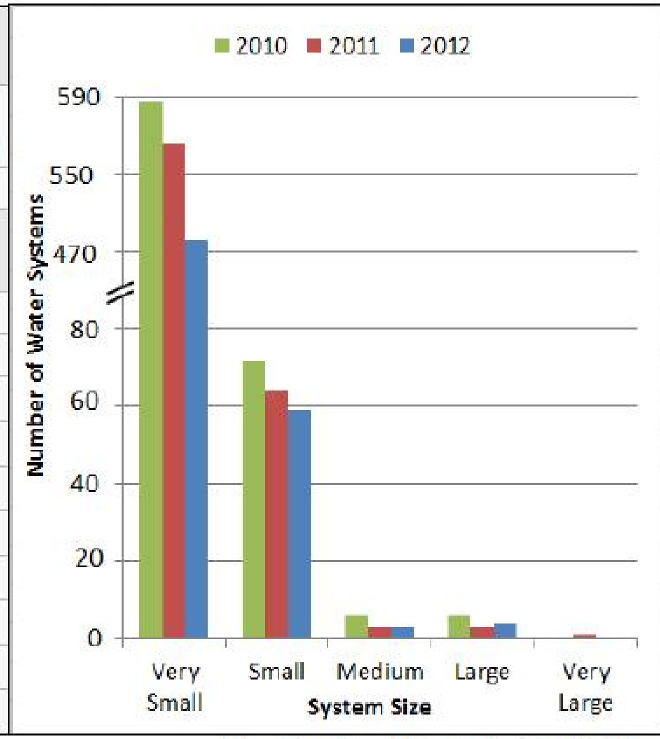

Reported Nitrate MCL Violations in 2011 (U.S. EPA)
2011 Nitrate MCL Violations
0
20
40
60 Mi
0
30
60
90 Km
http://groundwaternitrate.ucdavis.edu
Center for Watershed Sciences
99
5
101
58

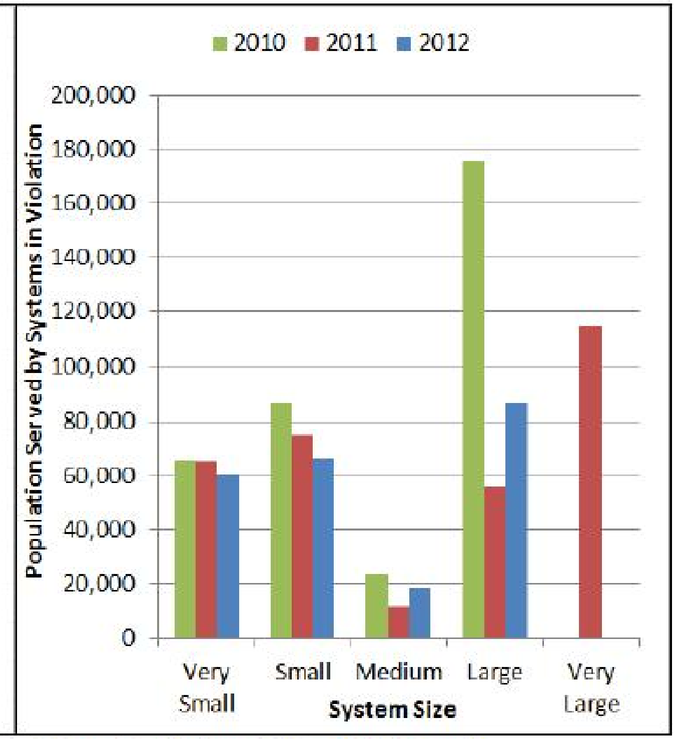


99
5
101
58
High Nitrate
Maximum [mg/L as Nitrate]
45 - 65
65 - 100
100 - 150
150 - 300
300 - 402
0 20 40 60 Mi
0 30 60 90 Km
http://groundwaternitrate.ucdavis.edu

USEPA SDWIS MCL Violations

2012 Nitrate MCL Violations		
	Total # Systems	Total Population
United States	**539**	**231,470**
States with the Greatest Number of Systems in Violation		
California	79	38,948
Texas	78	44,878
Nebraska	34	8,566
Washington	34	4,812
Pennsylvania	32	5,789
Kansas	31	25,579
Indiana	28	4,843
Oklahoma	22	18,188
Maryland	22	2,843
Minnesota	21	4,517

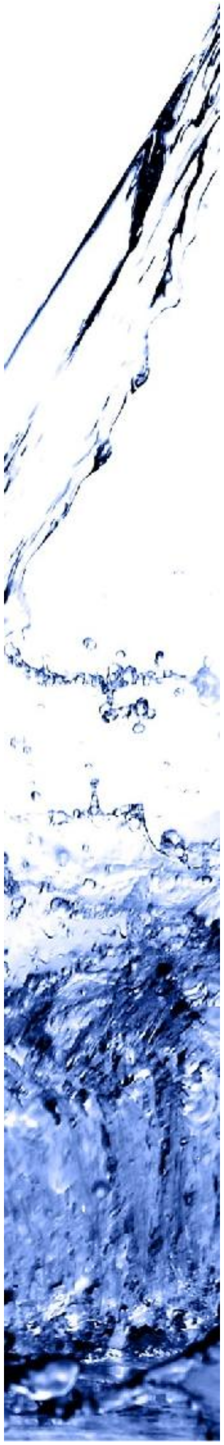


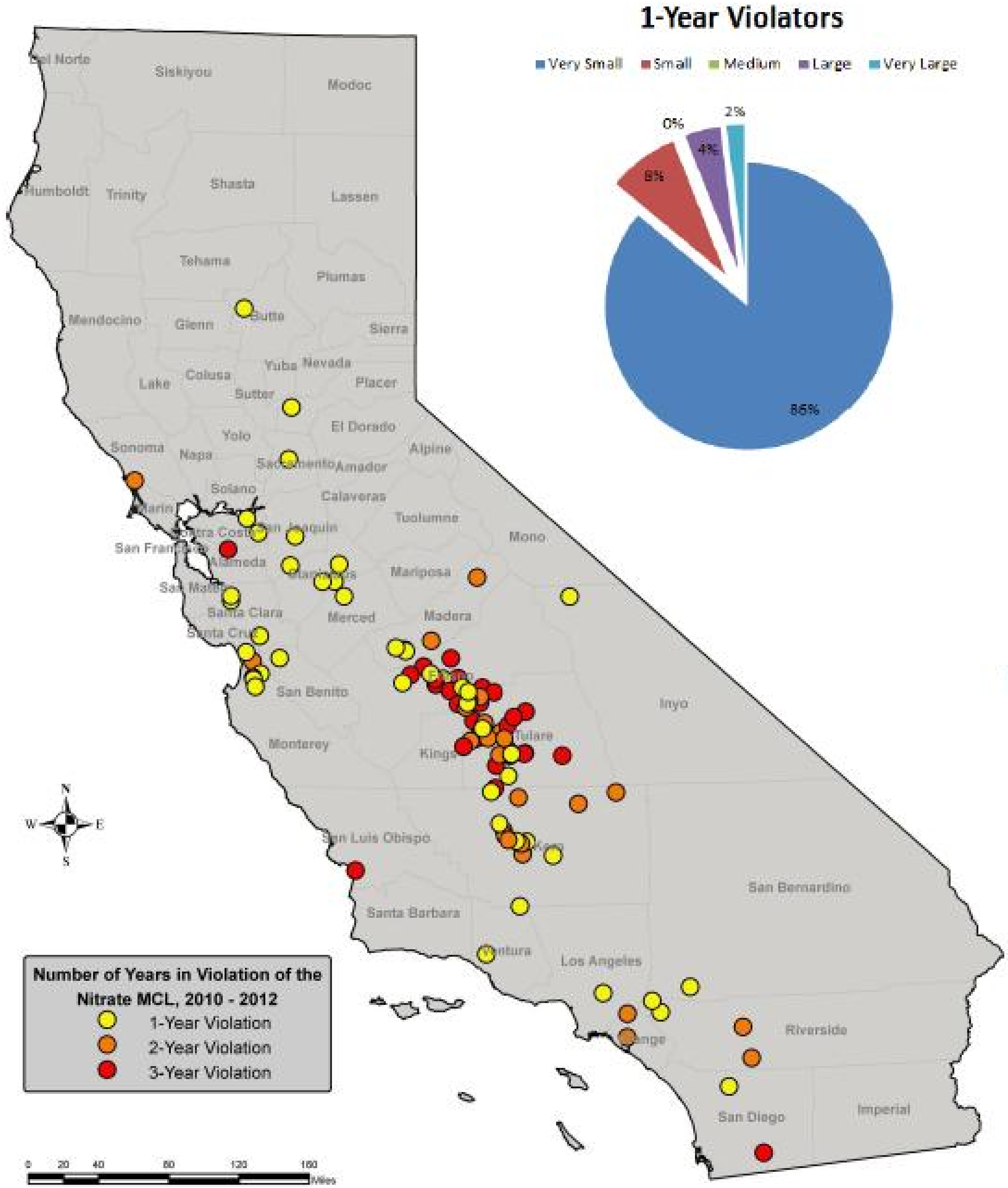


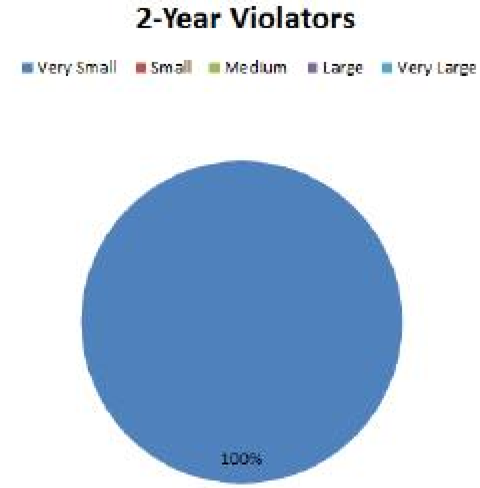
Very Small: <= 500 people, Small: 501 – 3,300 people, Medium: 3,301 – 10,000 people
Large: 10,001 – 100,000 people, Very Large: > 100,000 people

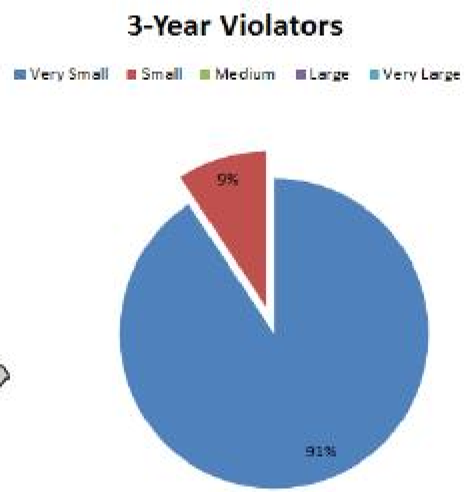
Source: V. Jensen and J. Darby, *Nitrate Impacted Water Systems – A National Perspective*, AWWA Inorganic Contaminants Workshop, 2013.

CDPH MCL Violations



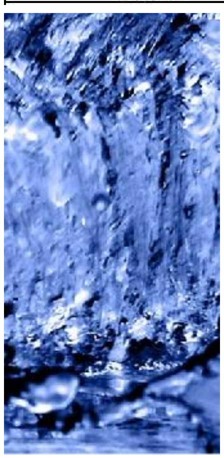




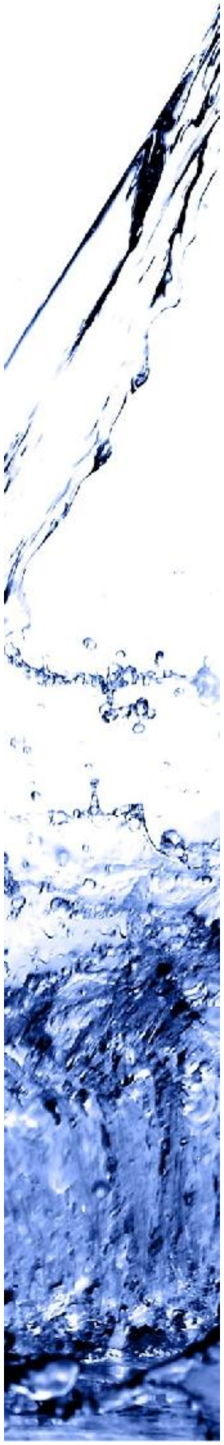


CDPH MCL Violations

NUMBER OF REPORTED SYSTEMS WITH NITRATE VIOLATIONS IN CALIFORNIA						
Year	Very Small	Small	Medium	Large	Very Large	**Total**
Population	*<= 500*	*501 – 3,300*	*3,301 – 10,000*	*10,001 – 100,000*	*> 100,000*	
2010	50	6	-	1	-	**57**
2011	67	4	-	-	1	**72**
2012	75	3	-	1	-	**79**
POPULATION SERVED						
2010	6,412	6,125	-	92,158	-	**104,695**
2011	8,928	3,700	-	-	114,840	**127,468**
2012	9,336	2,452	-	27,160	-	**38,948**



Source: V. Jensen and J. Darby, *Nitrate Impacted Water Systems – A National Perspective*, AWWA Inorganic Contaminants Workshop, 2013.



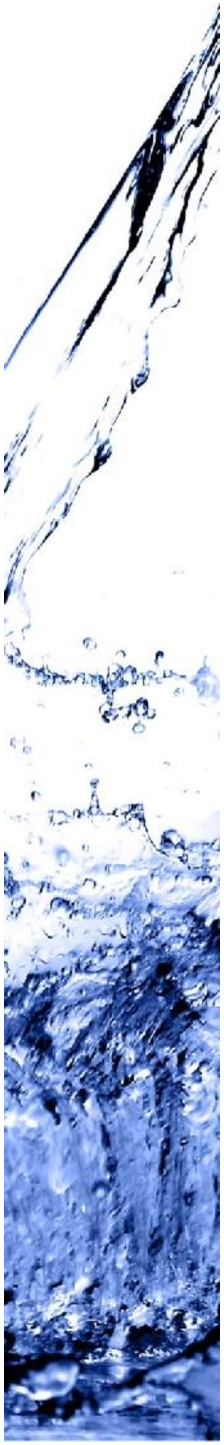
Summary of Nitrate Management Options

Non-Treatment Options

- Well Abandonment
- Wellhead Protection and Land Use Management
- Alternative Sources and Source Modification
- Blending

Treatment Options

- Nitrate Removal
  - Ion Exchange
    - Conventional, Specialized Resin, Counter Current, Multiple Vessel Configuration, WBA IX
  - Reverse Osmosis
    - Process & Membrane Improvement and Modification
  - Electrodialysis
    - EDR
    - SED
- Hybrid Systems
- Nitrate Reduction
  - Biological Denitrification
    - Fixed Bed
    - Fluidized Bed
    - MBR/MBfR
  - Chemical Denitrification
    - ZVI
    - SMI
    - Other Media



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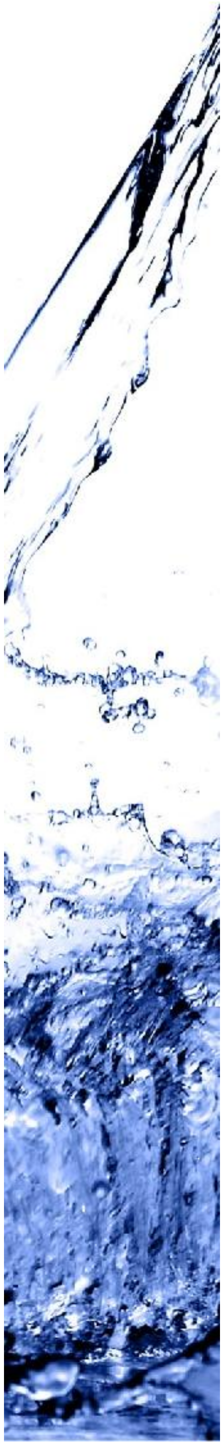
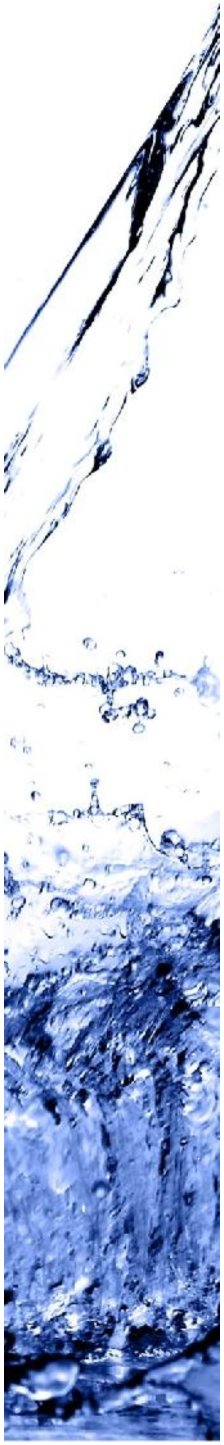


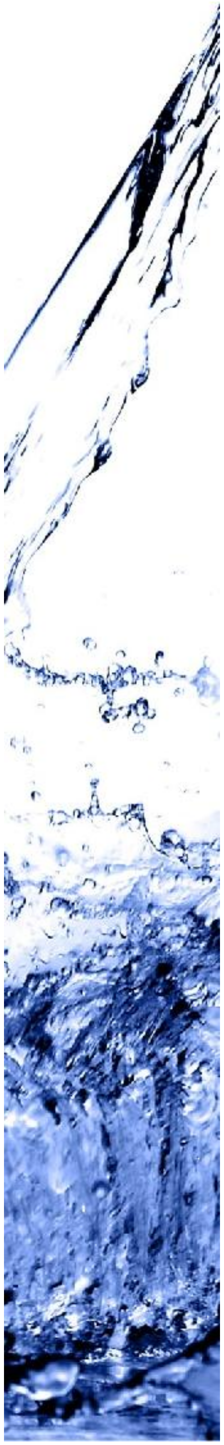
Well Abandonment

- Requires adequate capacity from other wells
- Need to follow appropriate abandonment procedures
- Recent AWWA Survey
  - ~ 30% respondents opt for abandonment



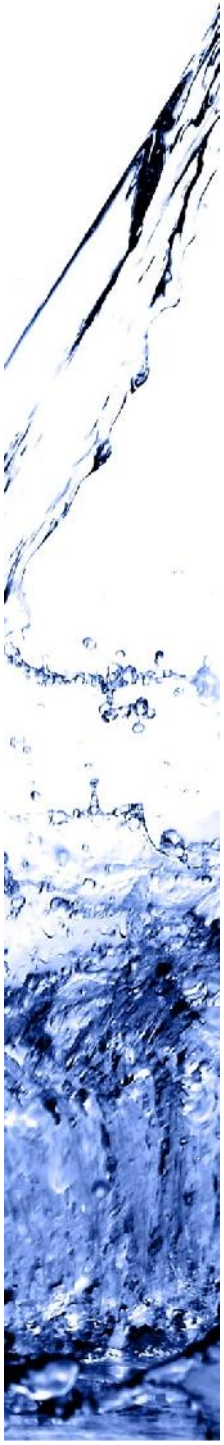
Wellhead Protection and Land Use Management

- Will not immediately eliminate need for treatment
- Can minimize source water nitrate over time
- Focuses on BMPs
  - Agricultural practices, dairy management, septic tanks mitigation

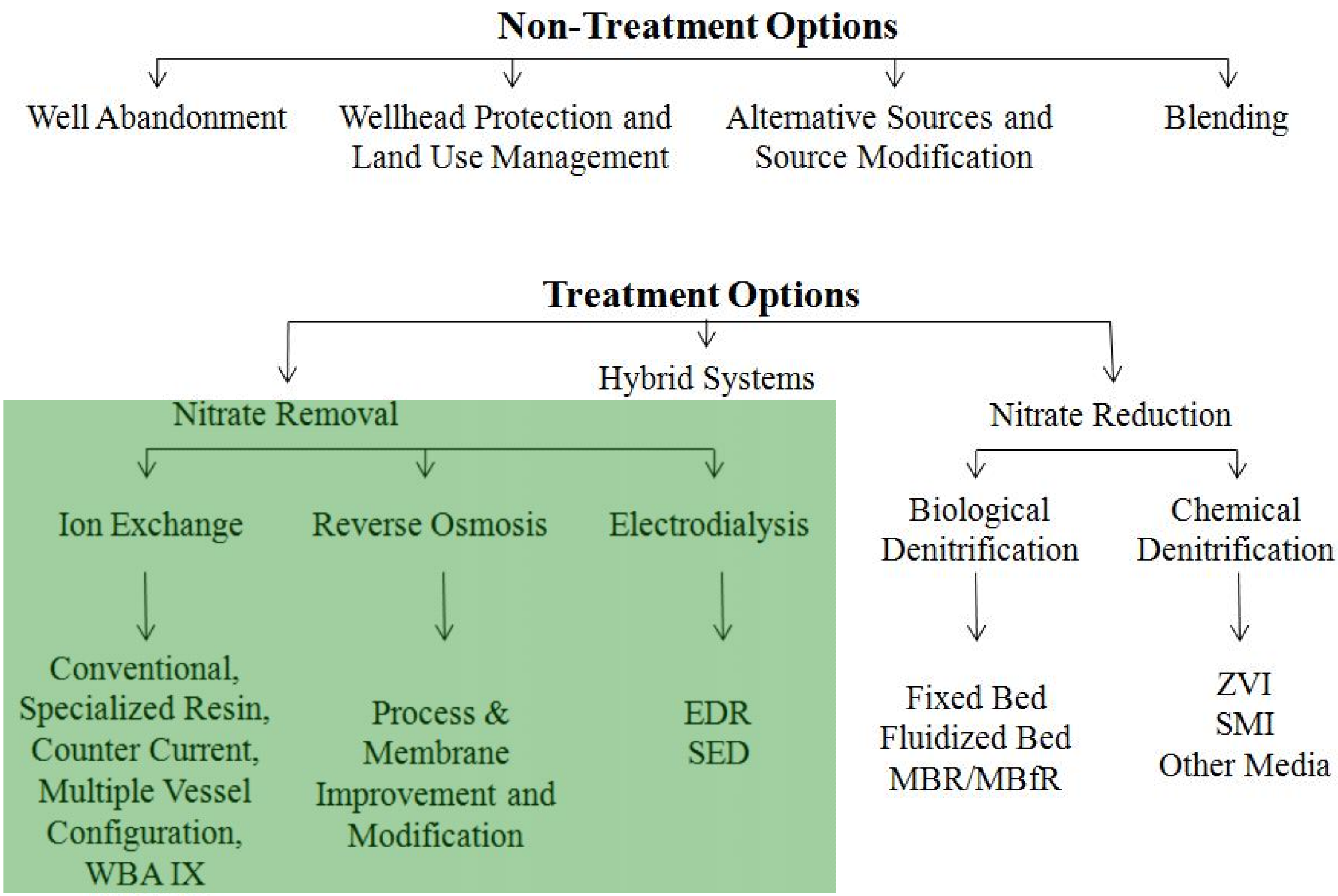


Blending

- Nitrate dilution via an alternate source
- Relies on availability of low nitrate sources
- Recent AWWA Survey
  - > 50% respondents opt for blending
- Requires capital investment and increased monitoring



Treatment Options: Nitrate Removal



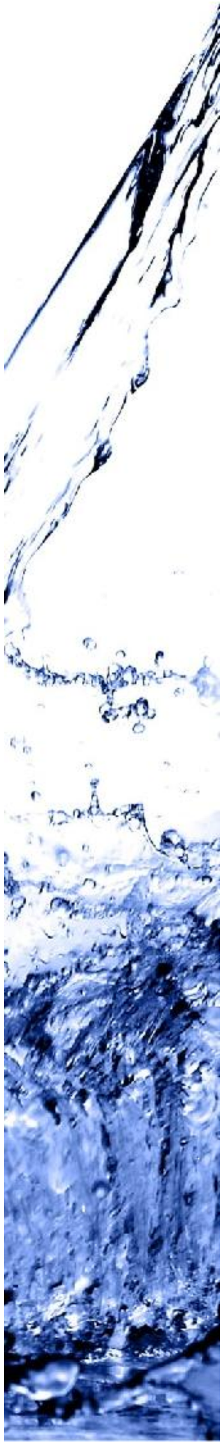
Removal Technologies

Source: Siemens

Source: Dow Chemical

Source: PC Cell

- Ion Exchange
  - Nitrate displaces chloride on anion exchange resin
  - Resin regeneration with brine solution
  - Limitations: sulfate, resin fouling, brine disposal
- Reverse Osmosis
  - Water pushed through membrane
  - Contaminants rejected
  - Limitations: membrane fouling, pretreatment, brine disposal
- Electrodialysis
  - Electric current governs ion movement
  - Anion and cation exchange membranes
  - Limitations: operationally complex, concentrate disposal



Treatment Options: Nitrate Reduction

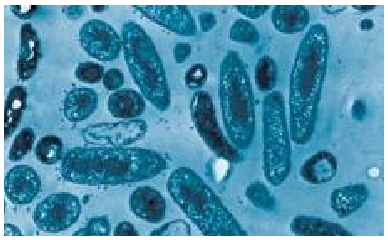
Non-Treatment Options

- Well Abandonment
- Wellhead Protection and Land Use Management
- Alternative Sources and Source Modification
- Blending

Treatment Options

- Nitrate Removal
  - Ion Exchange
    - Conventional, Specialized Resin, Counter Current, Multiple Vessel Configuration, WBA IX
  - Reverse Osmosis
    - Process & Membrane Improvement and Modification
  - Electrodialysis
    - EDR
    - SED
- Hybrid Systems
- Nitrate Reduction
  - Biological Denitrification
    - Fixed Bed
    - Fluidized Bed
    - MBR/MBfR
  - Chemical Denitrification
    - ZVI
    - SMI
    - Other Media

Reduction Technologies



Source: AnoxKaldnes

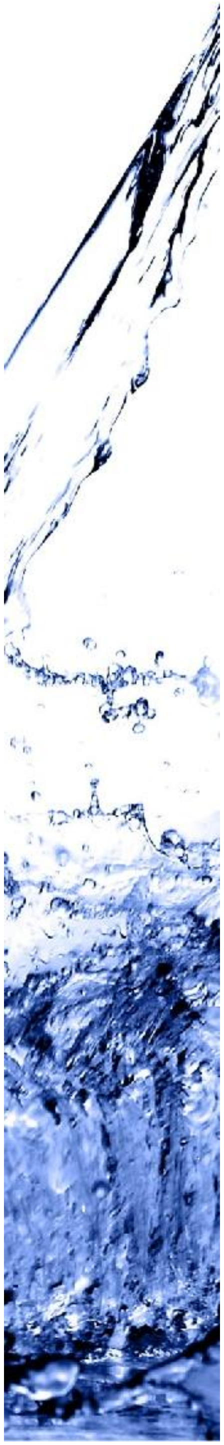
- Biological Denitrification
  - Bacteria transform nitrate to nitrogen gas
  - Anoxic conditions
  - Requires electron donor (substrate)
  - Limitations: lack of U.S. full scale systems, substrate requirement, post-treatment (filtration, disinfection)

Source: Hepure Technologies

- Chemical Denitrification
  - Metals reduce nitrate to ammonia (typically)
  - Zero-valent iron (ZVI)
  - Catalytic denitrification
  - Limitations: pilot studies only, intermediate reduction to ammonia, dependence on temperature and pH

POU/POE

- Point-of-Use (POU)
  - Under the sink, treatment of only potable water
- Point-of-Entry (POE)
  - Household treatment, treatment of all water
- Use of POU/POE is governed by CDPH regulations
- Primary option for household self-supply treatment



Treatment Options

Concerns	IX	RO	EDR	BD	CD
High Nitrate Removal					
High TDS Removal					
Arsenic Removal					
Radium and Uranium Removal					
Chromium Removal					
Perchlorate Removal					

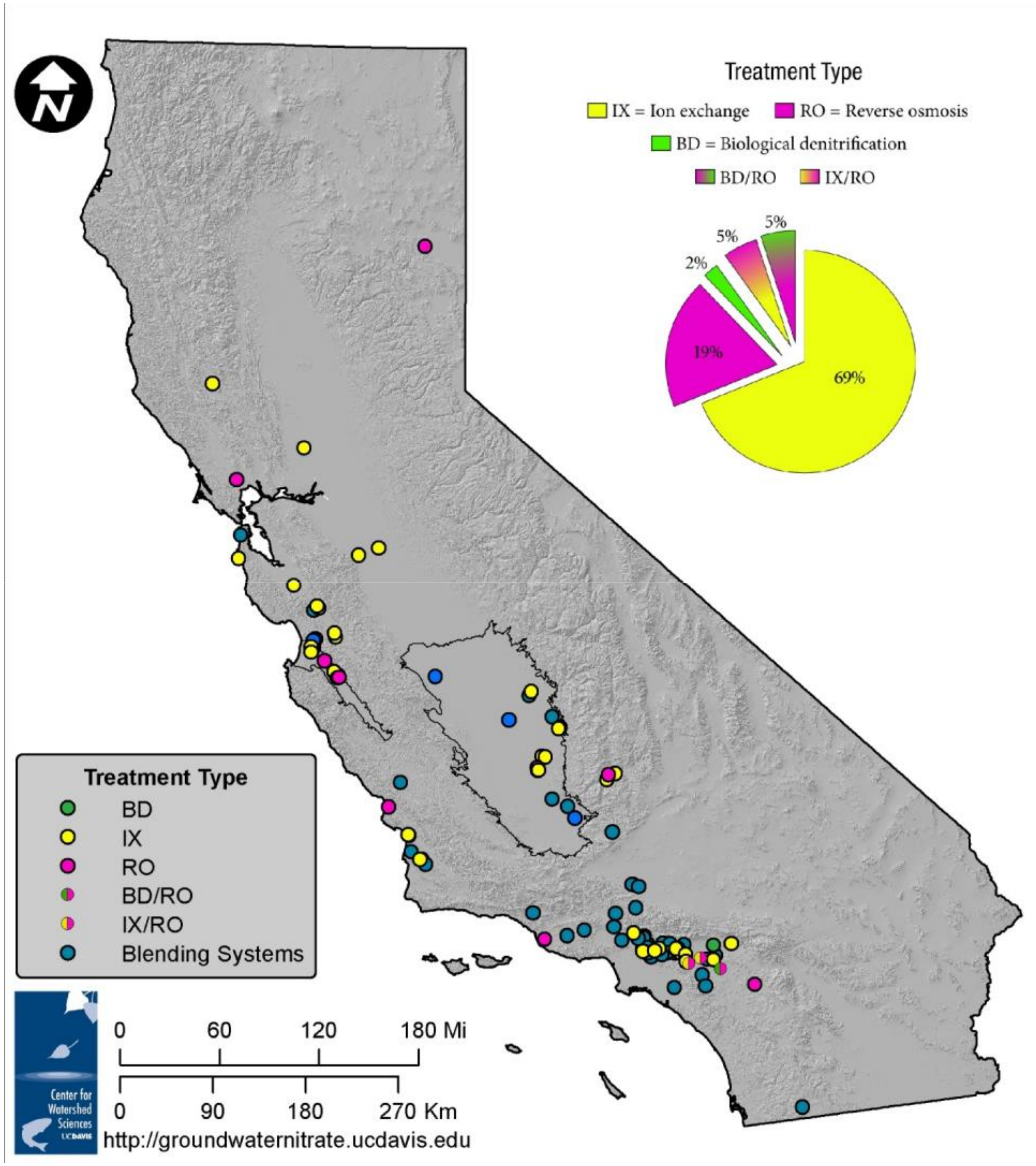
Good	→	Poor	Unknown (blank)

Priorities	IX	RO	EDR	BD	CD
High Hardness Not a Major Concern					
Reliability					
Training/ Ease of operation					
Minimize Capital Cost					
Minimize Ongoing O&M Cost					
Minimize Footprint					
Industry Experience					
Ease of Waste Management					

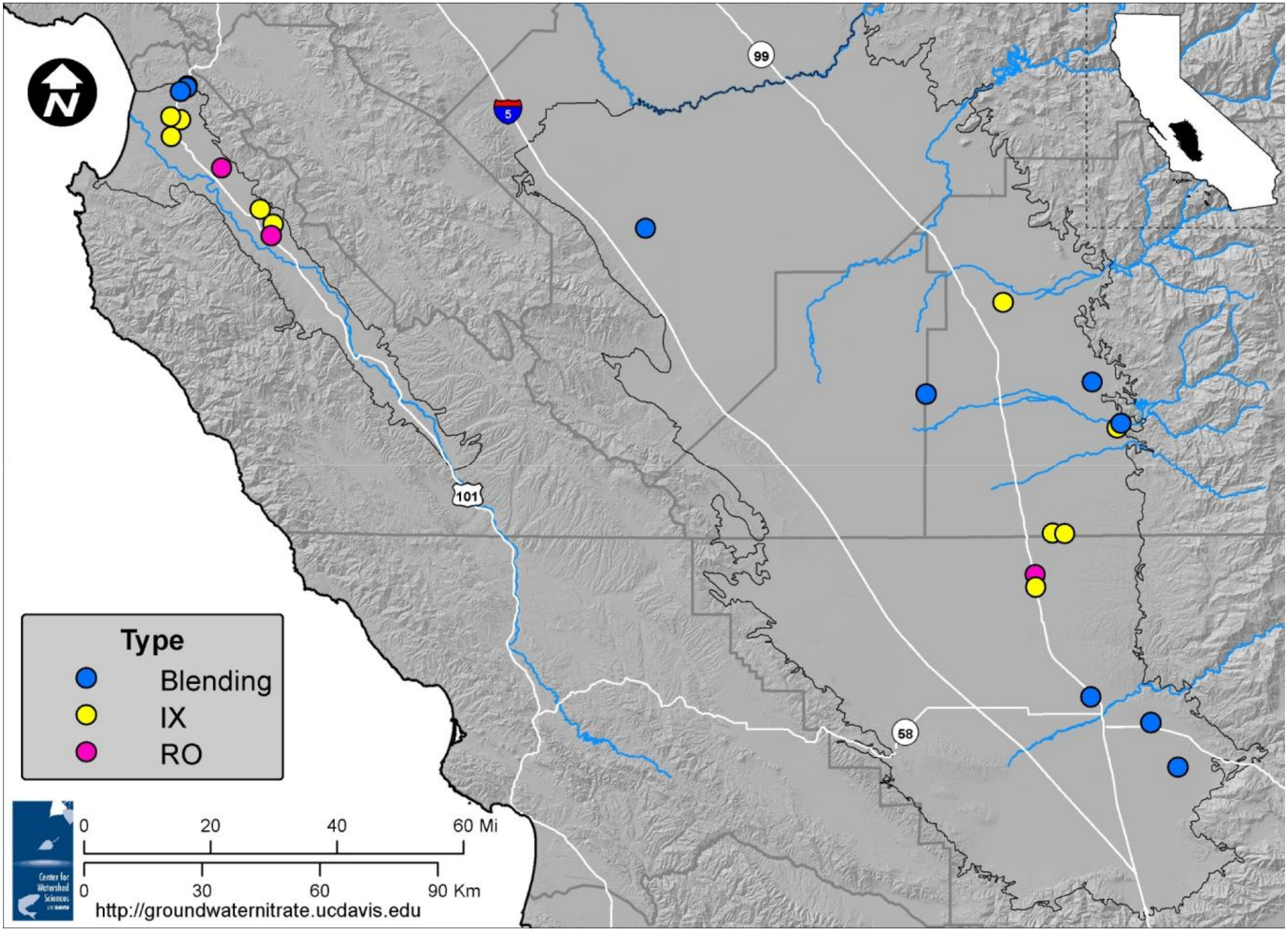
1 Ion Exchange (IX), Reverse Osmosis (RO), Electrodialysis Reversal (EDR), Biological Denitrification (BD), Chemical Denitrification (CD). This table offers a generalized comparison and is not intended to be definitive; there are notable exceptions to the above classifications.

Treatment Selection

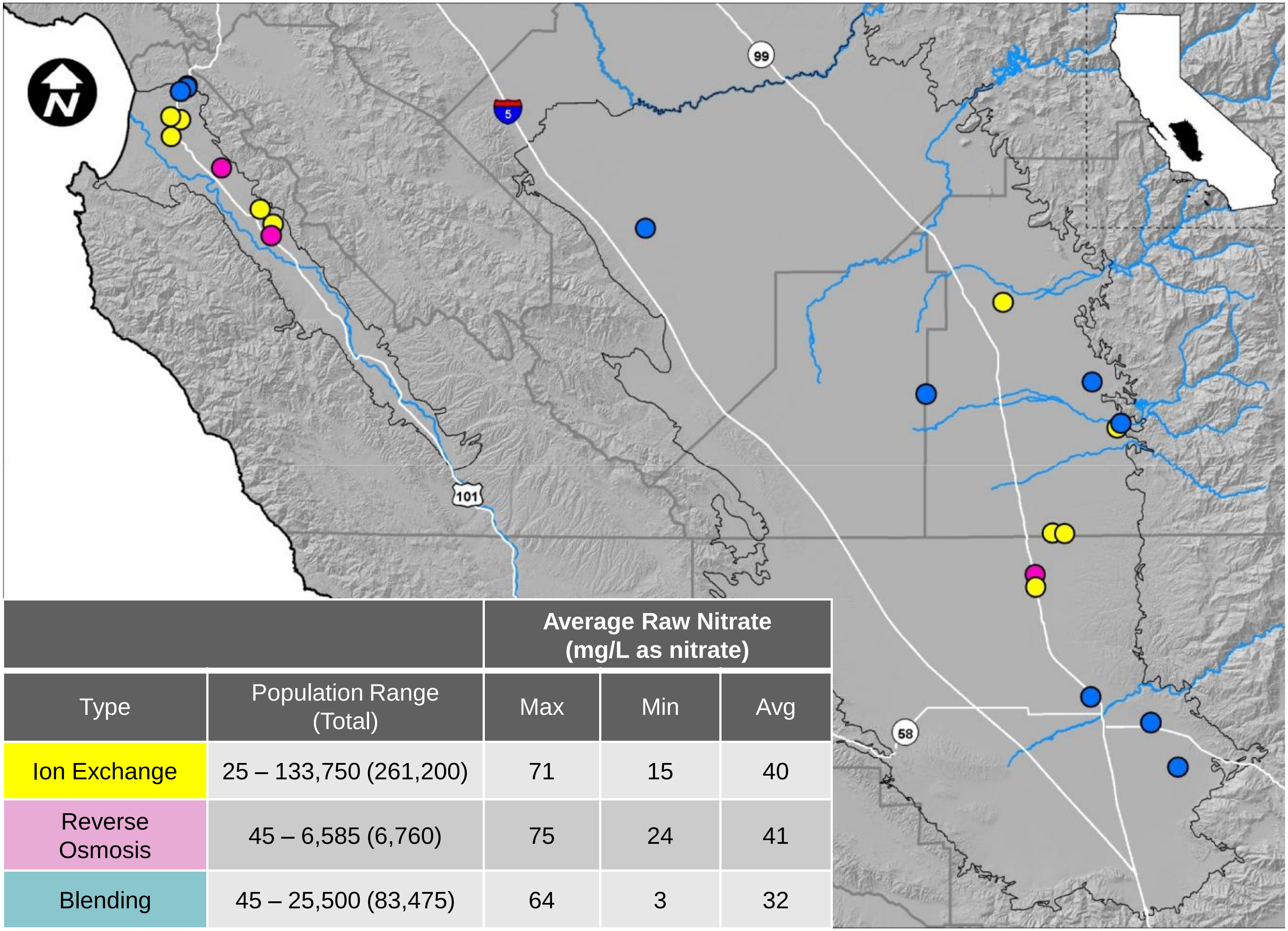
Option	Practical Nitrate Range	Considerations
Blend	10-30% above MCL	Dependent on capacity and nitrate level of blending sources.
Ion Exchange	Up to 2X MCL	Dependent on regeneration efficiency, costs of disposal and salt usage. Brine treatment, reuse, and recycle can improve feasibility at even higher nitrate levels.
Reverse Osmosis	Up to many X MCL	Dependent on availability of waste discharge options, energy use for pumping, and number of stages. May be more cost-effective than IX for addressing very high nitrate levels.
Biological Denitrification	Up to many X MCL	Dependent on the supply of electron donor and optimal conditions for denitrifiers. Start-stop mode needed, particularly for single well systems. May be more cost-effective than IX for addressing high nitrate levels.



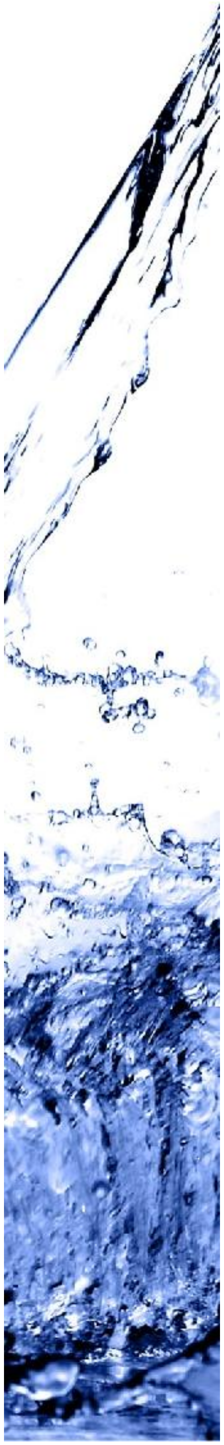
Treatment Type
IX = Ion exchange
RO = Reverse osmosis
BD = Biological denitrification
BD/RO
IX/RO
5%
5%
2%
19%
69%
Treatment Type
BD
IX
RO
BD/RO
IX/RO
Blending Systems
0
60
120
180 Mi
0
90
180
270 Km
Center for Watershed Sciences
http://groundwaternitrate.ucdavis.edu



Type
Blending
IX
RO
99
5
101
58
0
20
40
60 Mi
0
30
60
90 Km
http://groundwaternitrate.ucdavis.edu

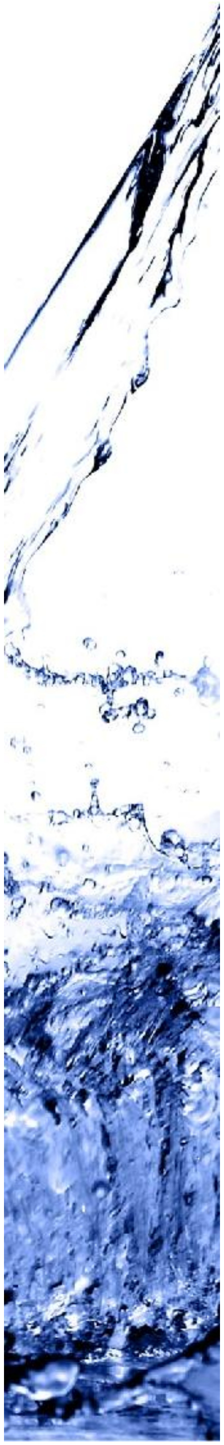


		Average Raw Nitrate (mg/L as nitrate)		
Type	Population Range (Total)	Max	Min	Avg
Ion Exchange	25 – 133,750 (261,200)	71	15	40
Reverse Osmosis	45 – 6,585 (6,760)	75	24	41
Blending	45 – 25,500 (83,475)	64	3	32



Conclusions

- **IX and RO** dominate current installations
  - Improvements in brine management in development and likely to increase feasibility and decrease costs
- **EDR** treatment for nitrate typically coupled with high TDS
  - SED may offer a more efficient option



Conclusions

- **Biological denitrification** has been implemented at full-scale in California; continued improvement anticipated as systems mature
- **Chemical denitrification** shows promise; however, further research, development and testing needed

Conclusions

- Brine reuse and treatment vital for continued IX implementation
- Multiple contaminant removal requirements can drive selection; best treatment option for nitrate may not be the most viable overall
- Site constraints can also drive selection
  - Land availability
  - Brine disposal options